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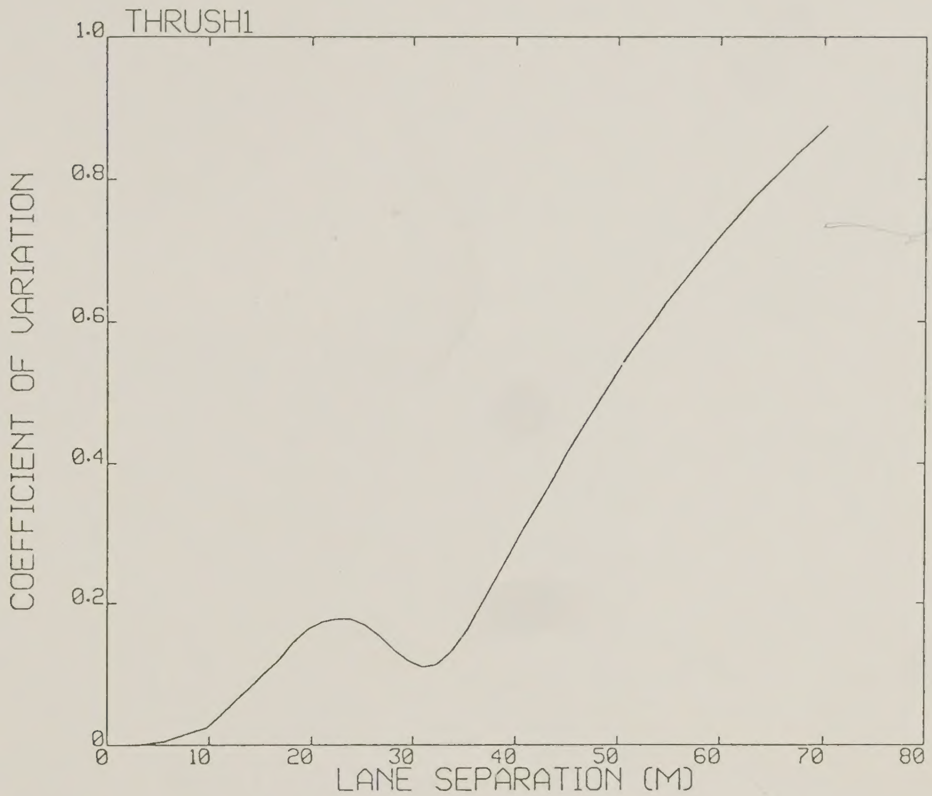
Swath Width Evaluation



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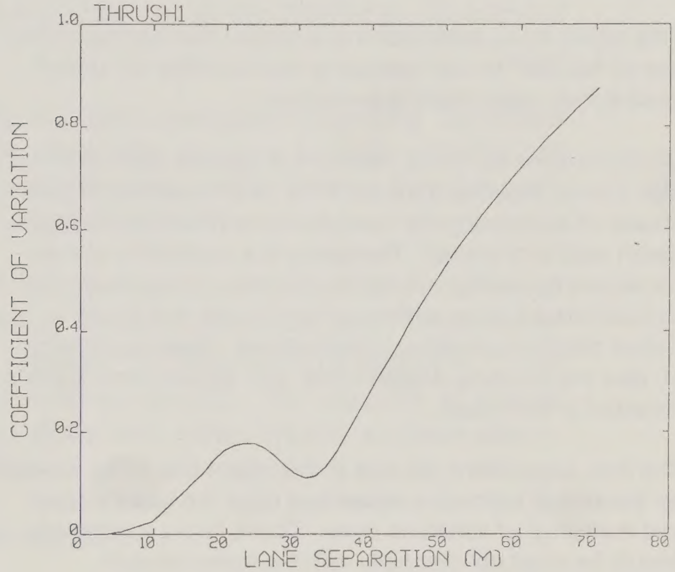

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Pesticide Precautionary Statement

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

Caution: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Foreword

This report is the culmination of a project demonstrating the use of AGDISP to evaluate spray swath widths for aircraft used during gypsy moth suppression.

On September 20, 1989, the team of authors was asked by Max Ollieu, Assistant Director FPM, to utilize AGDISP as a means of addressing the need for more information about swath widths of aircraft. Reviewing the availability of data necessary to use the model, the team found that swath evaluations could be performed for 16 aircraft but with limited nozzle-formulation combinations. Results, in terms of, lane separations, droplet sizes, and droplet densities, are provided in this report.

The lane separations derived in this report should be viewed as theoretical estimates dependent upon the exact aircraft and metrological variables used. These lane separations should be used operationally with the same caution extended to the use of any model projection.

The authors gratefully acknowledge the efforts of Tim McConnell, USDA Forest Service, Forest Pest Management, Portland, Oregon for his assistance in generating AGDISP input files. Mr. McConnell also provided information regarding aircraft specifications and insecticide use. The involvement of Mr. McConnell also demonstrates the nationwide interest in aerial spray improvement.

The authors also wish to recognize the assistance of Mr. Arnold McDonald, of Salish Kootenai College, Pablo, Montana in generating AGDISP input files. Part of Mr McDonalds' participation was as a training exercise in the use of AGDISP.

In addition, the information and advice provided by several people contributed greatly to the success of this project. They are Dr. Jon Bryant, Dr. Karl Mierzejewski, and Dr. Richard Reardon.

Lastly, the authors wish to thank Mr. Jack Barry, USDA Forest Service, for his support in this project.

EXECUTIVE SUMMARY

Deposition predictions by the computer program AGDISP are used to evaluate swath widths for selected aircraft spraying selected material in the Northeast to combat gypsy moth.

AGDISP predicts the motion of aerially released material, including the mean position of the material and the position variance about the mean as a result of turbulent fluctuations. The USDA Forest Service has been largely responsible for funding the code development and validation of AGDISP over the last eight years.

Sixteen aircraft (both helicopter and fixed-wing) were selected for this initial swath width evaluation. Data on these aircraft were readily available from the open literature or spray operators. Three deposition tank mixes -- Dimilin®, Undiluted Bt Foray 48L®, and 1 to 1 Diluted Bt Foray 48L® -- were released from these aircraft. The paucity of nozzle wind tunnel data on drop size distribution for these three tank mixes creates a sparse matrix with which to predict swath width using AGDISP.

In this report the following conclusions are reached:

1. Swath width predictions, generated from a lane separation methodology, generally show larger values than the APHIS swath width guidelines.

2. AGDISP code inputs for the swath width predictions are based on conservative assumptions on aircraft characteristics and atmospheric conditions. Swath widths for conditions other than those assumed in this report can be expected to be larger than the predictions shown herein.

3. Several aircraft inputs are very operator-specific (for example, the location of the spray boom on a helicopter). Other configurations of the same aircraft (with the same flight speed) will cause minor changes to the present results. Swath width predictions shown herein may be approximate in these alternate configurations.

From this report the following recommendations are evident:

1. Limited information is available on drop size distribution patterns from the more commonly used spray nozzles. Water-like material (Dimilin®) can be interpolated (and carefully extrapolated) from a known database of tunnel data as a function of flight speed. The same cannot be said for the Bt products. Any significant extension of the present work has to include a matrix of wind tunnel tests to determine drop size distribution patterns on anticipated spray materials. Aircraft flight speed is a significant data parameter.

2. Swath width is based on a lane-separation argument using relative standard deviation (coefficient of variation). The parametric level chosen in this report is consistent with best estimates found in the literature. Other swath width arguments would modify the results presented herein.

3. AGDISP was modified on the minicomputer at Continuum Dynamics, Inc. to recover nonvolatile deposition and automatically generate a complete drop size distribution in one computer run. These features should be implemented into the Data General and personal computer versions of the code so that any significant extension to the present work would not be restricted to the Continuum Dynamics, Inc. computer.

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1. INTRODUCTION

For the last fifteen years the United States Department of Agriculture Forest Service and the United States Army have been pursuing the development of computer codes to predict the deposition distribution of aerially released material. The two current codes under review are AGDISP (Teske, Ref. 1) and FSCBG (Curbishley and Skyler, Ref. 2). A complete description of the AGDISP model may be found in Bilanin, et al. (Ref. 3). Validation of the code may be found in Teske (Refs. 4, 5 and 6).

AGDISP is based on a Lagrangian approach to the solution of the released material equations of motion, and includes simplified models for aircraft wake and ambient turbulence effects. The AGDISP code tracks the motion of a group of similar sized particles or droplets released in the atmosphere from specified nozzle locations. Similar sized droplets are combined in a drop size distribution to generate the spray droplet cloud. The novel feature of the AGDISP code is that the dispersion of the group of similar droplets resulting from turbulent fluid fluctuations is quantitatively computed as the group of droplets descends toward the ground. The accuracy to which AGDISP can compute dispersion of this group of similar droplets is intimately related to a specification of the turbulent fluid fluctuations through which the droplets must pass, and the local fluid velocities in the vicinity of the aircraft releasing the material. The material is followed until it deposits on the ground or through the canopy; several data presentation options are then available to discern the final pattern of the material deposited on the ground or through the canopy.

Three terms are commonly used to describe the spray droplet cloud emitted at the aircraft and deposited on the ground or through the canopy:

1. Swath pattern is a description of the distribution of the spray deposit from one flight line, measured in terms of droplets, volume, active ingredient, or mass per unit area. The most desirable pattern is one in which spray deposition is nearly uniform across the swath, although this pattern is rarely achievable in practice.

2. Swath width is that portion of the pattern considered usable to achieve the objectives of spraying. Swath width for a particular aircraft is dependent upon desired spray drop size distribution, nozzle type and location, aircraft flight speed and release height, the formulation being sprayed, and ambient wind conditions. All inputs in theory influence swath width.

3. Lane separation is the operational distance between successive flight lines. Its importance lies in the desire to minimize deposition variation across flight lines. Lane separation is derived by overlapping single flight-line deposition results until an overlap distance is obtained that minimizes variation.

Swath width and lane separation for aircraft commonly used during gypsy moth (*Lymantria dispar L.*) spray programs are evaluated in this report. The simulation model AGDISP is used to conduct the evaluation.

Swath widths extrapolated for gypsy moth spraying have been previously described by the Animal Plant Health Inspection Service (Ref. 7). This description was based upon spray droplet distributions observed on flat deposit cards. Lane separation (as described herein) was not considered in the APHIS swaths. The purpose of the present study is to evaluate swath widths using a current numerical deposition model, and compare this evaluation with currently accepted APHIS guidelines.

The present study provides a theoretical basis for swath width evaluation.

This report describes swath width and lane separation using the mathematical simulation of spray droplet behavior as developed in AGDISP. Since the publication of the APHIS description of swath width, new tools have been developed that permit a more rigorous evaluation of swath. These tools utilize the theoretical approach (AGDISP) and the field approach (image analysis of collected drops using the "Swathkit" for example). There are advantages and disadvantages to both techniques.

One of the advantages of the theoretical approach is that the components of variations in swath pattern can be held constant. Aircraft, nozzle, and meteorological effects upon swath pattern can be evaluated and predicted because singular variables can be controlled. This level of control is not possible in a field approach because swath pattern during field evaluations is the sum total of all the variables operating upon it at any given moment. Field evaluations are generally unreplicable even in the same aircraft pass.

A disadvantage to the theoretical approach is that an exact swath pattern as predicted may never actually occur. It is a theoretical pattern resulting from controlled variables; many of these variables are uncontrolled during actual application.

The swath patterns and lane separations discussed in this report should be viewed as what can be predicted to occur with controlled variables. To that extent, these descriptions are benchmark estimates resulting from perfectly controlled conditions of temperature, wind speed and turbulence, relative humidity, aircraft flight speed and perfectly flown lane separations. They are benchmarks in that these predictions can be used as a theoretical starting point for spray swath analysis of these aircraft.

Swath width as considered by APHIS is probably based upon some reasonable expectation of droplet density (such as the lateral distance beneath the aircraft where 20 drops per square centimeter or more is present). Lane separation as defined herein is found from a purely overlap procedure. Swath width and lane separation should NOT be expected to be equal, but they should be consistent with each other. Lane separation should be slightly larger than swath width.

2. METHODOLOGY

This report examines swath width as defined by lane separation for a number of selected aircraft operating in the Northeast. Data on these aircraft were readily available as the AGDISP calculations were assembled. The aircraft, and their anticipated effective swath widths (Ref. 7), are summarized in Table 1. Basic information about these aircraft were obtained from Hardy (Ref. 8), from the operators themselves, or approximated or assumed by the authors of this report. Table 2 summarizes all aircraft input data entered into AGDISP.

The spectrum of predictions possible in this report was limited by the lack of drop size distribution data characterizing the spray material released from the nozzles. A match of aircraft flight speeds, nozzle types and spray material resulted in a limited test matrix that includes the following:

1. The release of Dimilin®, a material that is assumed to behave like water (with a volatile fraction of 0.984) for nozzle types 8004, 8010 and 8020, with data interpolated and extrapolated from Yates, et al. (Ref. 9) for all aircraft in this report.

2. The release of Undiluted Bt Foray 48L® (company proprietary volatile fraction supplied by Bowen, private communication) for nozzle types 8003 and Micronair AU5000 (Harrison and Parkin, Ref. 10) for the Bell 206B, Bell 47G Soloy, and Hughes 500D.

3. The release of 1 to 1 Diluted Bt Foray 48L® for Micronair AU5000 (Harrison and Parkin, Ref. 10) for the Turbo Thrush.

Table 3 summarizes all drop size distribution data entered into AGDISP.

The following general assumptions are made for all input data into AGDISP:

1. The assumed spray release height is 50 feet except for the DC-3, Piper Aztec and Twin Beech, where the assumed spray release height is 75 feet. Deposition is predicted on the ground. If a canopy were present, the spray release height would be 50 feet above the canopy, and deposition would be at the canopy crown.

2. Aircraft weight is assumed to be the empty weight plus one-half the useful payload weight as recorded in Hardy (Ref. 8).

3. Atmospheric conditions consist of a three MPH head wind at 50 feet above the ground (average recorded wind speed for gypsy moth spray projects 1986-1988). An ambient temperature of 61 deg F and ambient relative humidity of 64 percent (average recorded values for gypsy moth spray projects 1986-1988) give a wet bulb temperature depression for evaporative effects of 4.0 deg C.

4. All helicopter nozzles are assumed to be uniformly distributed along the boom from the center of the helicopter out to three-fourths of the rotor radius. All fixed-wing aircraft nozzles (except for Micronair) are assumed to be uniformly distributed along the trailing edge of the wing (with a horizontal boom) from a position close to the fuselage (in some cases specified by the operator) out to three-fourths of the aircraft semispan. All flat-fan nozzles are assumed to point 90 degrees to the free stream.

The assumption of uniform nozzle distributions enables a consistent representation of the swath width. Nozzle position corrections are generally made for propeller wash and

the presence of the fuselage, but these effects are not included here. To minimize the drift of small droplets, nozzles should be placed no further out than three-fourths of the helicopter rotor radius or aircraft semispan. Most of the nozzles in the field were positioned in this way.

With the input data in hand, it is then possible to exercise the AGDISP code to generate up to 16 predictions of spray material behavior, one for each drop size in the distribution, for each aircraft and each released material. A typical example is shown in Figure 1 for the Turbo Thrush spraying Dimilin®. Each drop size distribution generates a ground deposition pattern representing the summed mass fraction deposition of material by drop size (total mass fraction equals 1.0). For the trajectories of Figure 1, combined with drop size results not shown here, the resulting ground deposition patterns obtained are shown in Figure 2.

This procedure is repeated for every aircraft configuration for each released material. A total of 26 AGDISP computer runs are analyzed in the present effort.

TABLE 1
Aircraft Examined For Swath Width Study

Aircraft	APHIS Recommended Swath Width (feet) (Ref. 7)
AgCat A	75
AgCat Turbo	100
AgHusky	75
Air Tractor	100
Bell 204	120
Bell 206B	75
Bell 212	120
Bell 47G Soloy	75
DC-3	300
Hiller 12E	75
Hiller Soloy	75
Hughes 500D	75
Piper Aztec	100
Piper Brave	75
Turbo Thrush	100
Twin Beech	100

TABLE 2
Aircraft Input Data
A) Fixed-Wing

Aircraft	Wing Span (feet)	Height (feet)	Speed (MPH)	Weight (lbf)	Wing Area (sq ft)	Propeller (RPM)
AgCat A	42.4	50	80	5,023	401	2,300
AgCat Turbo	42.4	50	110	5,335	401	2,300
AgHusky	41.6	50	110	3,353	299	2,700
Air Tractor	45.2	50	120	5,700	366	1,675
DC-3	94.6	75	160	21,379	722	2,550
Piper Aztec	37.2	75	130	4,250	354	2,575
Piper Brave	38.8	50	120	3,672	346	2,500
Turbo Thrush	44.4	50	110, 120	6,050	401	2,000
Twin Beech	47.8	75	150	7,260	557	2,575

TABLE 2 (Continued)
Aircraft Input Data
B) Helicopter

Aircraft	Rotor Radius (feet)	Height (feet)	Speed (MPH)	Weight (lbf)	Rotor (RPM)	Boom Location (X, Y) (feet)
Bell 204	24.0	50	90	6,650	324	0.0, -9.2
Bell 206B	16.7	50	80	2,330	384	-1.3, -11.2
Bell 212	24.1	50	90	8,586	394	-3.0, -10.0
Bell 47G Soloy	18.6	50	65	2,422	394	-8.3, -8.2
Hiller 12E	17.7	50	60	2,430	394	-7.8, -9.1
Hiller Soloy	17.7	50	70	2,370	394	-5.0, -8.5
Hughes 500D	13.2	50	90	1,828	394	-1.2, -5.6 1.7m .4

Boom Location is its placement relative to the shaft centerline and blade plane of the helicopter; the first number is the axial position (negative forward); the second number is the vertical position (negative below).

TABLE 3
Nozzle Drop Size Mass Fraction Distribution Data
A) 8004 Dimilin®

Drop Size (microns)	Flight Speeds (MPH) 60	65	70	80	90	110	120
46.3	0.0071	0.0077	0.0083	0.0094	0.0106	0.0136	0.0155
73.7	0.0133	0.0147	0.0160	0.0188	0.0215	0.0308	0.0375
106.4	0.0223	0.0246	0.0269	0.0314	0.0360	0.0490	0.0574
138.6	0.0566	0.0625	0.0685	0.0803	0.0922	0.1299	0.1558
171.0	0.0751	0.0818	0.0885	0.1018	0.1152	0.1479	0.1674
203.4	0.0755	0.0805	0.0856	0.0957	0.1058	0.1409	0.1659
235.9	0.0792	0.0830	0.0867	0.0942	0.1017	0.1095	0.1098
268.3	0.0850	0.0912	0.0975	0.1101	0.1226	0.1122	0.0893
301.3	0.0951	0.0985	0.1019	0.1088	0.1156	0.0990	0.0756
334.8	0.0912	0.0901	0.0890	0.0867	0.0845	0.0660	0.0497
366.7	0.0936	0.0889	0.0842	0.0749	0.0655	0.0450	0.0337
398.2	0.0773	0.0712	0.0650	0.0528	0.0405	0.0226	0.0170
430.7	0.0571	0.0523	0.0476	0.0380	0.0285	0.0156	0.0121
463.2	0.0485	0.0444	0.0404	0.0322	0.0241	0.0128	0.0096
495.7	0.0302	0.0268	0.0235	0.0167	0.0100	0.0026	0.0020
528.7	0.0255	0.0226	0.0197	0.0138	0.0080	0.0018	0.0013

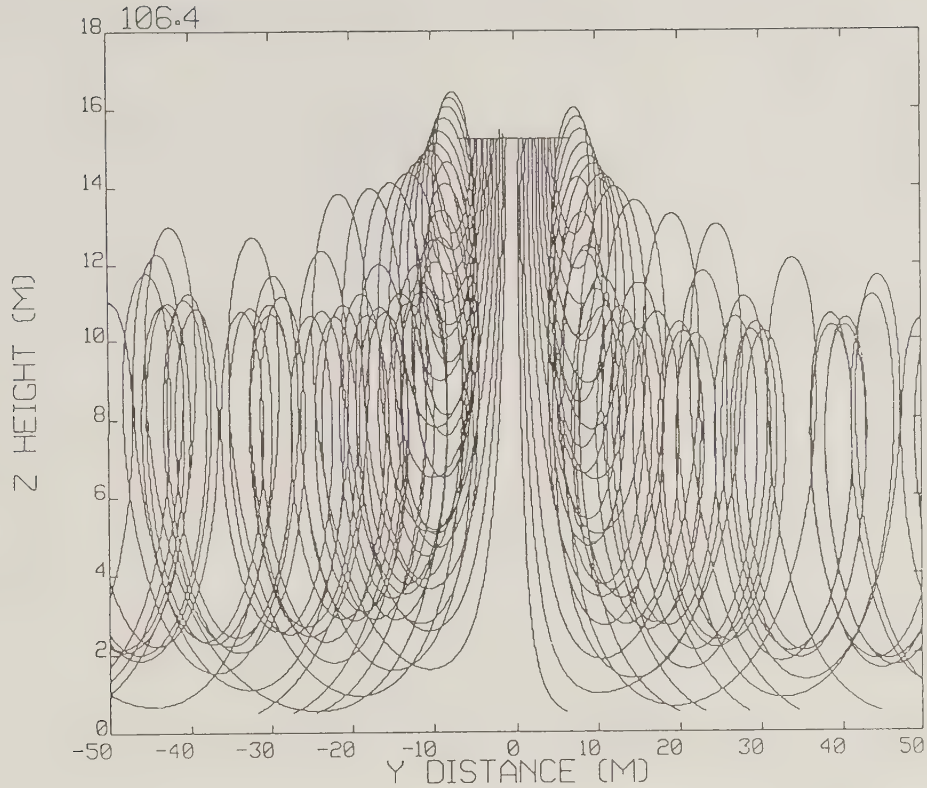
Drop Size is determined for each category by the volume-average formula found in Herdan (Ref. 11).

TABLE 3 (Continued)
Nozzle Drop Size Mass Fraction Distribution Data
B) 8010 and 8020 Dimilin®

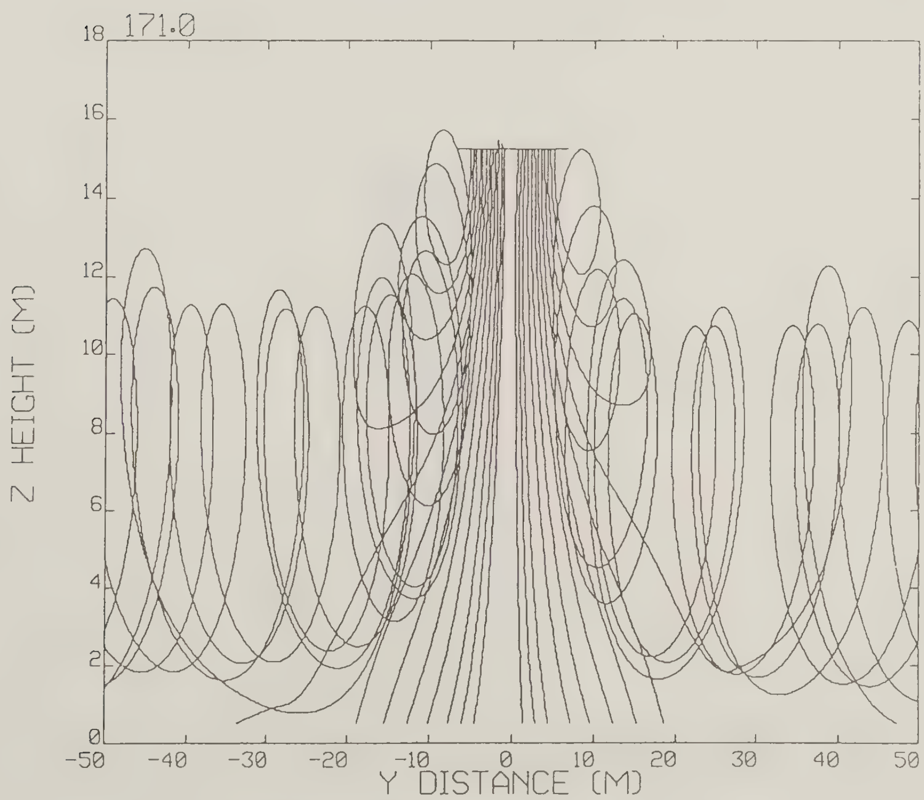
Drop Size (microns)	8010 Dimilin® 120	130	150	8020 Dimilin® 150	160
	Flight Speeds (MPH)				
46.3	0.0166	0.0188	0.0230	0.0115	0.0123
73.7	0.0313	0.0355	0.0441	0.0274	0.0300
106.4	0.0477	0.0516	0.0593	0.0521	0.0568
138.6	0.1147	0.1368	0.1810	0.1180	0.1282
171.0	0.1580	0.1808	0.2263	0.1649	0.1799
203.4	0.1528	0.1726	0.2120	0.1674	0.1857
235.9	0.1217	0.1331	0.1557	0.1697	0.1879
268.3	0.1010	0.0887	0.0642	0.0843	0.0815
301.3	0.0774	0.0557	0.0124	0.0267	0.0066
334.8	0.0534	0.0418	0.0187	0.0434	0.0351
366.7	0.0393	0.0269	0.0021	0.0080	0.0042
398.2	0.0327	0.0221	0.0009	0.0145	0.0077
430.7	0.0215	0.0145	0.0004	0.0358	0.0297
463.2	0.0097	0.0065	0.0001	0.0422	0.0427
495.7	0.0108	0.0072	0.0000	0.0014	0.0038
528.7	0.0046	0.0031	0.0000	0.0325	0.0340

TABLE 3 (Continued)
Nozzle Drop Size Mass Fraction Distribution Data
C) 8003 and AU5000 Bt Foray 48L®

Drop Size (microns)	8003 Undiluted			AU5000 Undiluted	AU5000 1 to 1
	Flight Speeds (MPH)				
	65	80	90	110	110
28.0	0.0120	0.0110	0.0103	0.0670	0.0490
56.6	0.0460	0.0443	0.0432	0.1600	0.1390
85.7	0.1370	0.1277	0.1214	0.2500	0.2620
115.0	0.2120	0.1990	0.1903	0.2390	0.2510
144.6	0.2060	0.1990	0.1943	0.1600	0.1610
174.0	0.1330	0.1360	0.1380	0.0740	0.0720
203.4	0.0500	0.0573	0.0622	0.0290	0.0290
233.0	0.0330	0.0430	0.0497	0.0110	0.0140
262.8	0.0200	0.0317	0.0394	0.0070	0.0070
292.8	0.0100	0.0190	0.0250	0.0030	0.0030
322.7	0.0130	0.0183	0.0219	0.0010	0.0010
352.7	0.0110	0.0163	0.0199	0.0010	0.0020
382.7	0.0210	0.0240	0.0260	0.0000	0.0010
412.7	0.0230	0.0220	0.0213	0.0000	0.0040
442.7	0.0330	0.0253	0.0202	0.0000	0.0030
488.1	0.0150	0.0100	0.0067	0.0000	0.0020

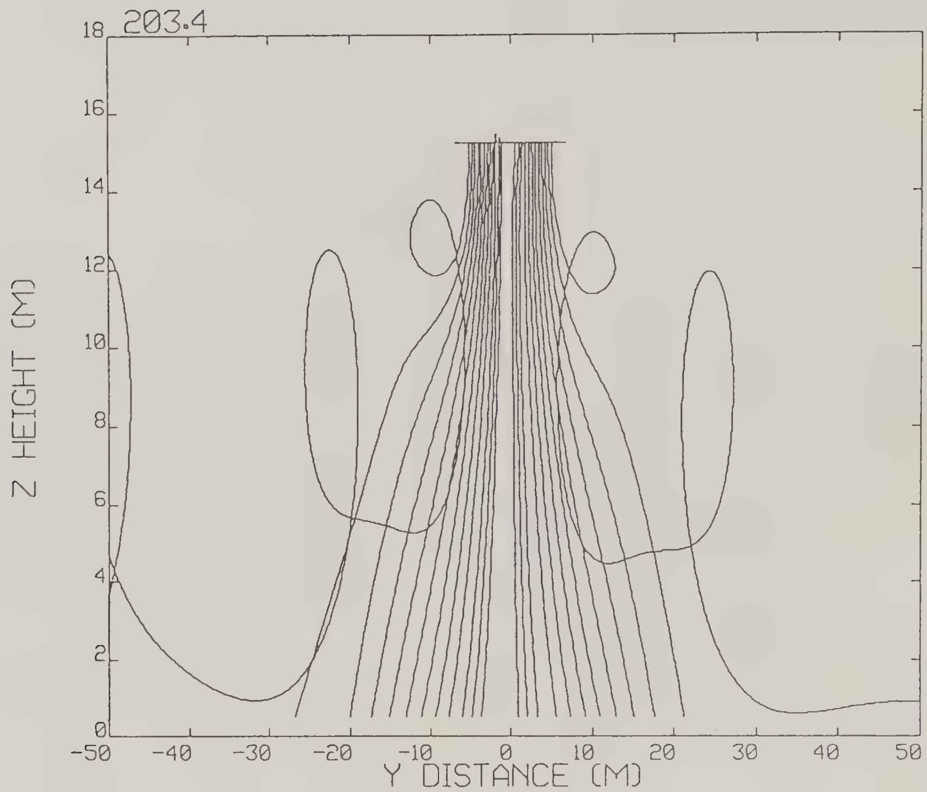


A) Initial drop size of 106.4 microns.

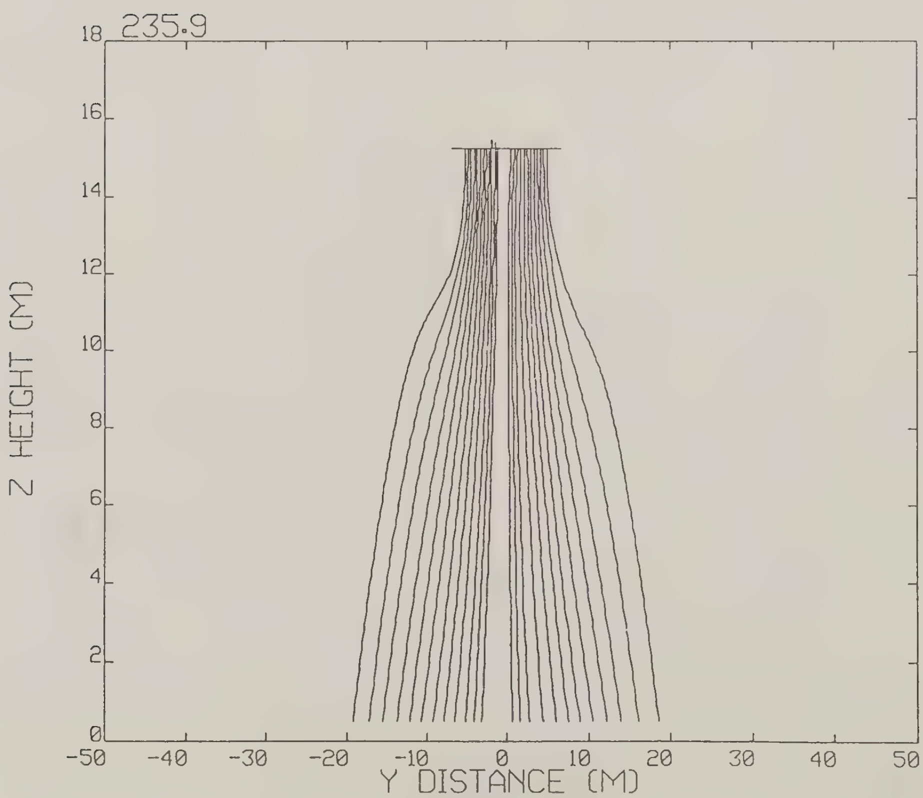


B) Initial drop size of 171.0 microns.

Figure 1. Typical trajectory patterns for four drop sizes released from nozzles located along the wing of a Turbo Thrush (Dimilin®).

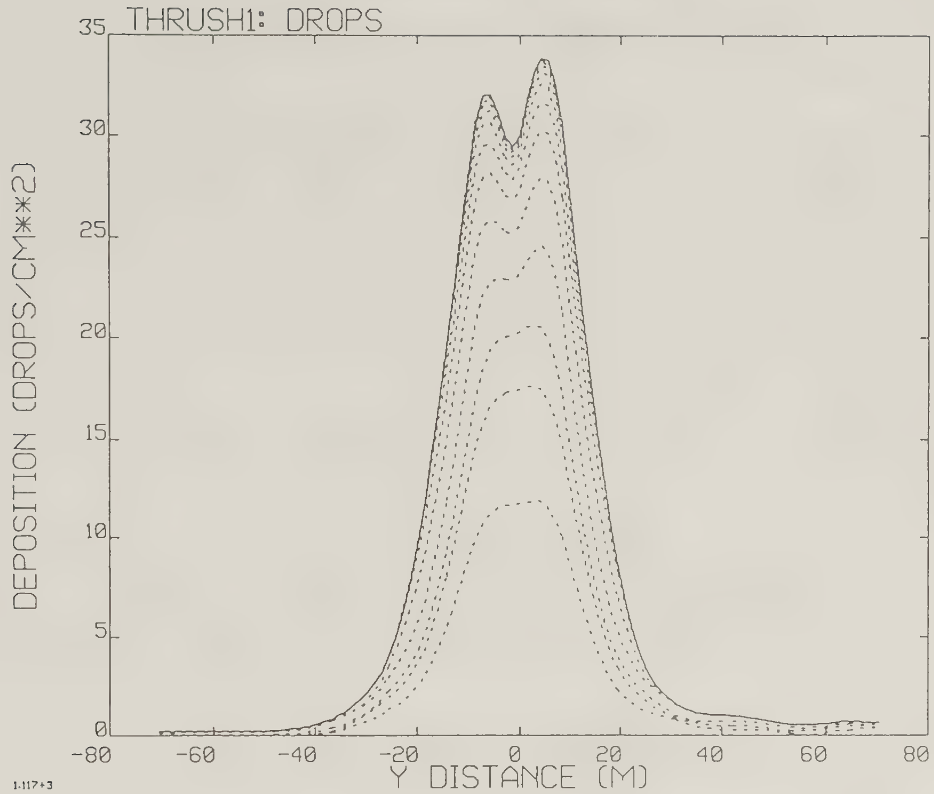


C) Initial drop size of 203.4 microns.

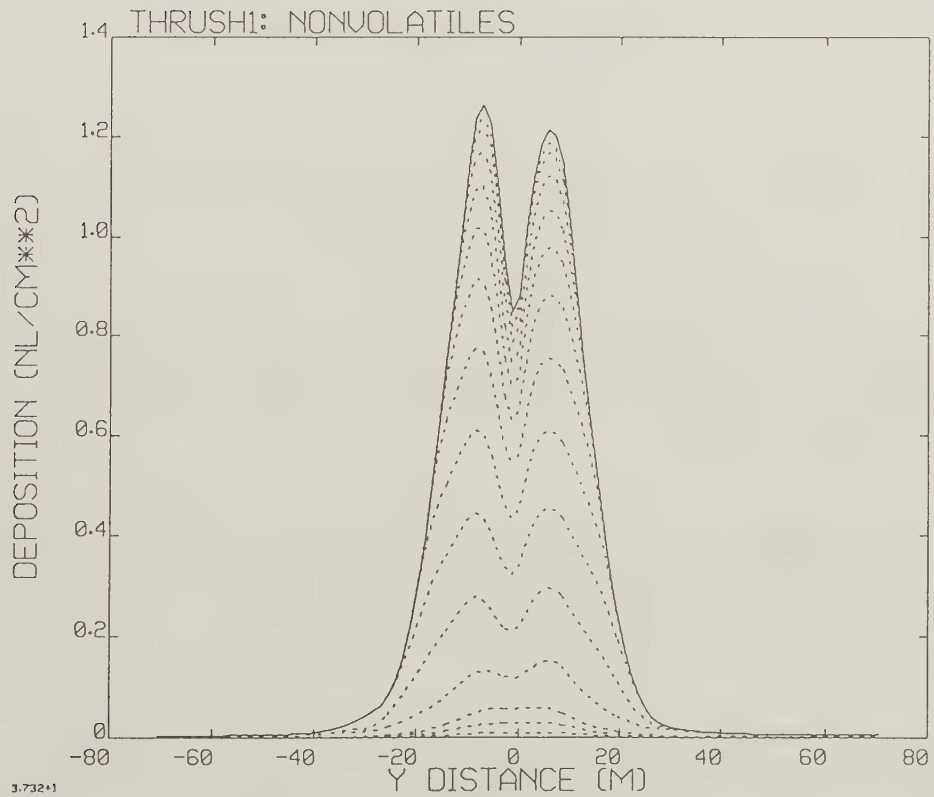


D) Initial drop size of 235.9 microns.

Figure 1 (Cont'd). Typical trajectory patterns for four drop sizes released from nozzles located along the wing of a Turbo Thrush (Dimilin®).



A) Deposition in drops per square centimeter.



B) Deposition of nonvolatiles in nanoliters per square centimeter.

Figure 2. Composite ground deposition for the summed drop size distributions released from nozzles on the Turbo Thrush (Dimilin®).

3. LANE SEPARATION RESULTS

Lane separation is determined by examining the deposition of nonvolatiles as illustrated in Figure 2B.

The most logical way of determining lane separation is to take the single flight-line deposition results from AGDISP and overlap the results at different spacings to construct the overall deposition (Quantick, Ref. 12). Each combined deposition pattern is identical to the single flight-line deposition, but offset by lane separation. For helicopters and twin-engine fixed-wing aircraft, the flight direction over these additional flight lines is immaterial; however, for the single-engine fixed-wing aircraft, it is assumed that the aircraft are flying in the same direction rather than To and Fro.

Calculations are performed by a computer program that operates on the deposition results from AGDISP to generate the relative standard deviation, or coefficient of variation, defined by:

$$\text{COV} = \text{coefficient of variation} = \frac{1}{\overline{G}}\left[\frac{\sum (G_i - \overline{G})^2}{n-1}\right]^{1/2}$$

where

$$\overline{G} = \text{deposition mean} = \frac{1}{n}\sum G_i$$

$$G_i = \text{ground deposition value at location } i$$

$$n = \text{number of deposition values.}$$

The COV curve for the Turbo Thrush is illustrated in Figure 3. COV curves are noted for an increase in COV as lane separation increases from zero, to a local maximum value, then a drop to a local minimum value, and next a rise to large COV values as the overlapped depositions distance themselves from each other. This behavior is pronounced in the Turbo Thrush case, Figure 3A, because of the bimodal deposition predicted (Figure 2B). Many deposition patterns are overlapped for small values of lane separation. In a purely Gaussian (nominal or bell shaped) deposition distribution, only a smooth rise in COV is observed, indicating that the first local maximum is a result of the non-Gaussian deposition beneath the aircraft.

Previous work has focused on discerning the "optimum" lane separation by examining card deposition data (Parkin and Wyatt, Ref. 13). From these and other results, an acceptable value for COV may be taken as 0.3 for herbicide applications (Quantick, Ref. 12), extended to other deposition applications by Spillman (Ref. 14). For the present report a COV value of 0.3 is used to determine lane separation.

Figure 3A illustrates the procedure involved. The intersection point of COV = 0.3 is found by computer to give a lane separation of 40.7 meters (133 feet) in this example. The corresponding overlapped ground deposition profile is shown in Figure 3B. Using a COV of 0.3 for lane separation, it is then necessary to confirm that deposition within the overlapped pattern is above a predetermined acceptable threshold.

Consistent with lane separation is the overlapped values of average drops per square centimeter and nonvolatile nanoliters per square centimeter. For the purpose of this evaluation it is assumed by the authors that Dimilin® should be deposited 20 to 30 drops per square centimeter. A calculation performed by the authors suggests that the expected nonvolatile Bt deposition level for a 16 BIU application should be between 12 to 20 nanoliters per square centimeter consistent with Bryant and Yendol (Ref. 15). Volume median diameter (VMD) may also be computed for all deposited material, and is 250 to 350 microns for Dimilin® and 150 to 250 microns for Bt.

Table 4 summarizes all lane separation results developed in this report. The APHIS guidelines (from Table 1) may be seen to be conservative in nearly all cases, with the exception of the Bell 206B and the DC-3. An assumption inherent in these predictions is that there is no crosswind to drift the released material left or right of the flight line. Such drift would increase the swath width reported here, but would also decrease the average depositions given in Table 4.

Several results from Table 4 are somewhat surprising. The predicted AgCat A lane separation is significantly higher than the APHIS guidelines. This result may be attributed to the relatively low flight speed assumed (80 MPH); however, increasing the flight speed to 90 MPH, the lane separation results show little change (Table 5). Tip vortex strength is directly proportional to aircraft weight and inversely proportional to rotor diameter (or wing span) and aircraft flight speed

$$\Gamma = \text{tip vortex strength} = \frac{W}{\rho\, b\, U}$$

where

$$W = \text{aircraft weight}$$

$$\rho = \text{air density}$$

$$b = \text{rotor diameter or wing span}$$

$$U = \text{flight speed.}$$

A higher flight speed reduces the tip vortex strength; the weaker tip vortex in turn influences the material less, and a narrower lane separation should result. Unfortunately, the higher flight speed also changes the drop size distribution, which compensates for the tip vortex strength effect by distributing more material into the smaller drop sizes.

The DC-3 result shows a surprisingly low value for lane separation when compared with the APHIS guidelines. Increasing the release height to 100 feet does not change the lane separation (Table 5). Above a certain height, release height is no longer a variable since the tip vortices merely transport the released material vertically toward the ground. When the tip vortices are within one rotor diameter or one wing span of the ground, they will then begin to separate; at this point the spray material begins to deposit.

The Twin Beech results for the 8010 nozzle suggest a lane separation far higher than for the 8020 nozzle. The drop size distribution (Table 3) indicates that more spray material is present in the smaller drop sizes for the 8010 nozzle. This material has a

tendency to be influenced more by the tip vortices, and will deposit further from the aircraft centerline, increasing the swath width.

Results for the Turbo Thrush for undiluted and diluted Bt suggest insufficient average deposit when a COV of 0.3 is used as the criterion for lane separation. In this case it may be thought that lane separation must be tightened in order to assure that the deposition threshold criterion of 12 to 20 nanoliters per square centimeter is met. This is not the case, however, since a smaller lane separation implies a lower nozzle flow rate which implies less material on the ground. The average deposition of ten and eight nanoliters per square centimeter in Table 4 remains fairly constant until the lane separation is well below APHIS guidelines. Rather, the aircraft flight speed should be increased to reduce the tip vortex strength, shorten the swath width and improve deposition. Unfortunately, the drop size distribution for the Micronair AU5000 nozzle for a flight speed other than 110 MPH is not available. However, if the 110 MPH data is used but the aircraft is flown at 120 MPH, the corrected results shown in Table 5 are obtained. Lane separation is reduced but the average deposition is unchanged. This example illustrates that swath adjustments alone cannot correct deposit deficiencies. More importantly, once an acceptable swath pattern is achieved, flow rate should be used to increase deposit levels.

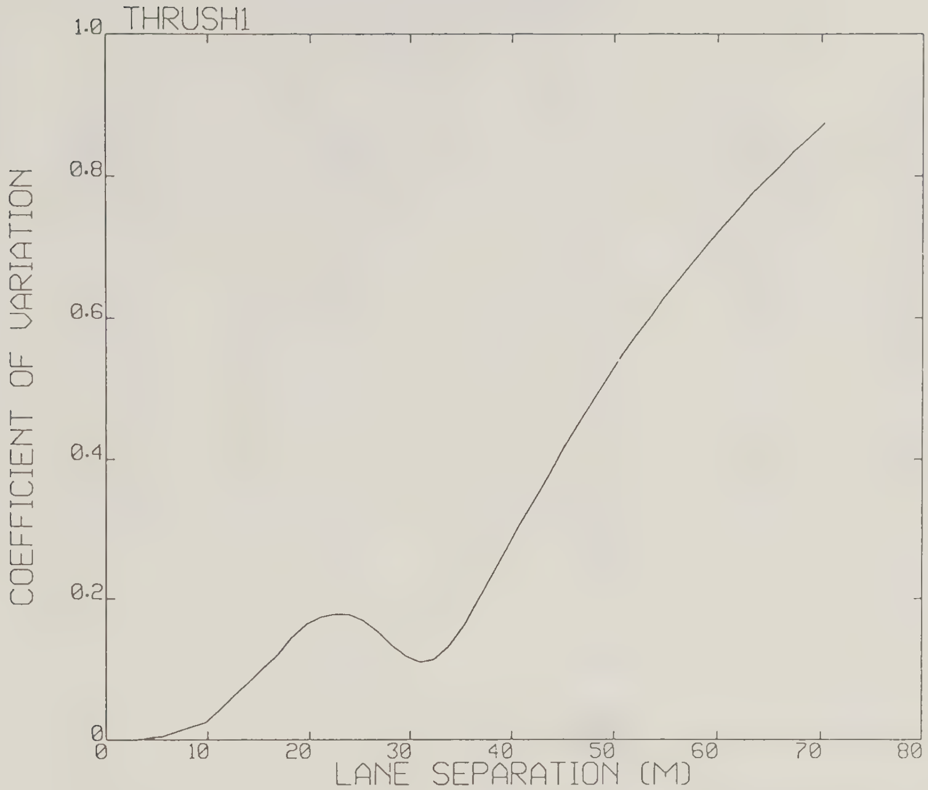
There are sufficient results for Dimilin® to consider whether the lane separation predictions may be collapsed onto one curve. If the aircraft effect is felt through the tip vortex strength Γ, lane separation may be nondimensionalized by rotor diameter or wing span b, and plotted as a function of Γ nondimensionalized by the product bU. The result is shown in Figure 4. The average value for lane separation is

$$\text{Lane Separation (for Dimilin}^{\circledR}) = 2.75\ b$$

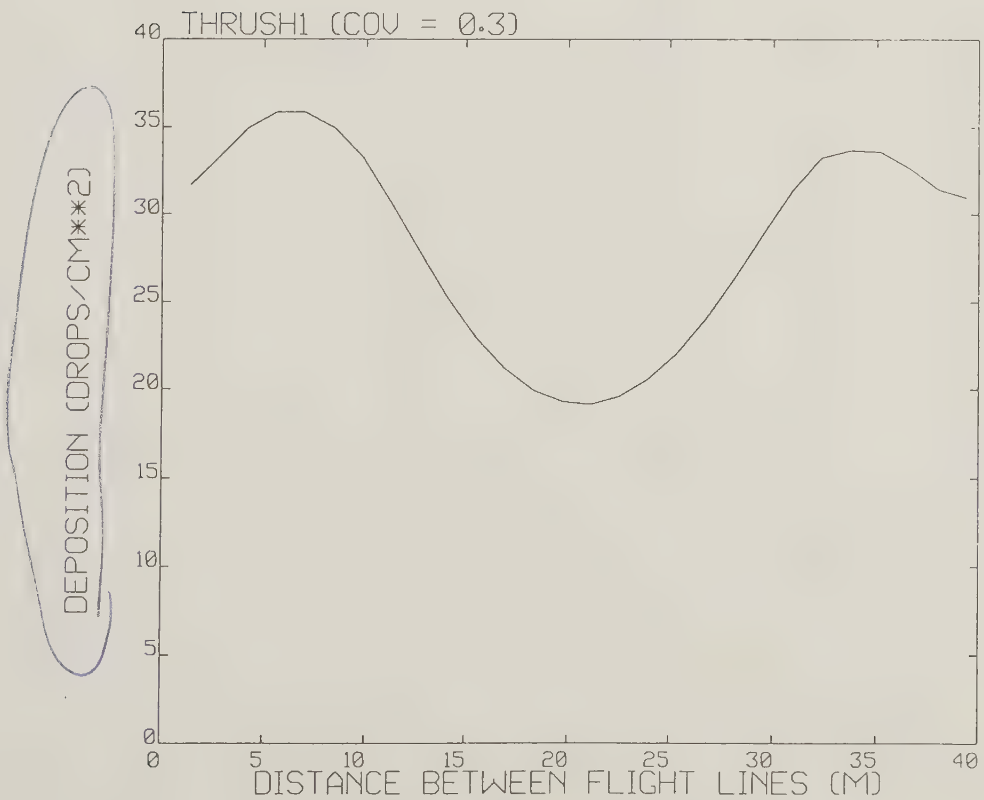
with

$$\text{Standard Deviation} = 0.43\ b\ .$$

The variability in Figure 4 is due principally to differences in drop size distribution and the effects of evaporation.



A) COV as a function of lane separation (Dimilin®).



B) Overlapped deposition for COV = 0.3 .

Figure 3. COV generated by lane separation variation for the Turbo Thrush.

This is not an AGDISP Plot - Mist generated Run COV in mass

TABLE 4
Lane Separation Results
A) Dimilin®

Aircraft	Speed (MPH)	Nozzle	Lane Separation (feet)	VMD (microns)	Ave. Dep. ($drops/cm^2$)
AgCat A	80	8004	126	303	23
AgCat Turbo	110	8004	126	258	36
AgHusky	110	8004	102	253	36
Air Tractor	120	8004	132	242	39
Bell 204	90	8004	125	278	30
Bell 206B	80	8004	68	293	31
Bell 212	90	8004	160	282	29
Bell 47G Soloy	65	8004	92	320	27
DC-3	160	8020	201	260	36
Hiller 12E	60	8004	96	326	28
Hiller Soloy	70	8004	87	311	28
Hughes 500D	90	8004	75	280	36
Piper Aztec	130	8010	127	243	43
Piper Brave	120	8004	113	241	41
Turbo Thrush	120	8010	133	258	37
Twin Beech	150	8010	145	191	51
Twin Beech	150	8020	127	272	34

TABLE 4 (Continued)
Lane Separation Results
B) Bt Foray 48L®

Undiluted

Aircraft	Speed (MPH)	Nozzle	Lane Separation (feet)	VMD (microns)	Ave. Dep. (nl/cm^2)
Bell 206B	80	8003	106	180	13
Bell 47G Soloy	65	8003	117	176	13
Hughes 500D	90	8003	107	177	13
Turbo Thrush	110	AU5000	215	98	10

1 to 1 Diluted

Aircraft	Speed (MPH)	Nozzle	Lane Separation (feet)	VMD (microns)	Ave. Dep. (nl/cm^2)
Turbo Thrush	110	AU5000	169	102	8

TABLE 5
Lane Separation Modifications
A) Dimilin®

Aircraft	Speed (MPH)	Nozzle	Lane Separation (feet)	VMD (microns)	Ave. Dep. (drops/cm^2)
AgCat A	90	8004	125	285	26
DC-3 (100 feet)	160	8020	206	275	35

B) Bt Foray 48L®

Undiluted

Aircraft	Speed (MPH)	Nozzle	Lane Separation (feet)	VMD (microns)	Ave. Dep. (nl/cm^2)
Turbo Thrush	120	AU5000	190	98	10

1 to 1 Diluted

Aircraft	Speed (MPH)	Nozzle	Lane Separation (feet)	VMD (microns)	Ave. Dep. (nl/cm^2)
Turbo Thrush	120	AU5000	168	104	8

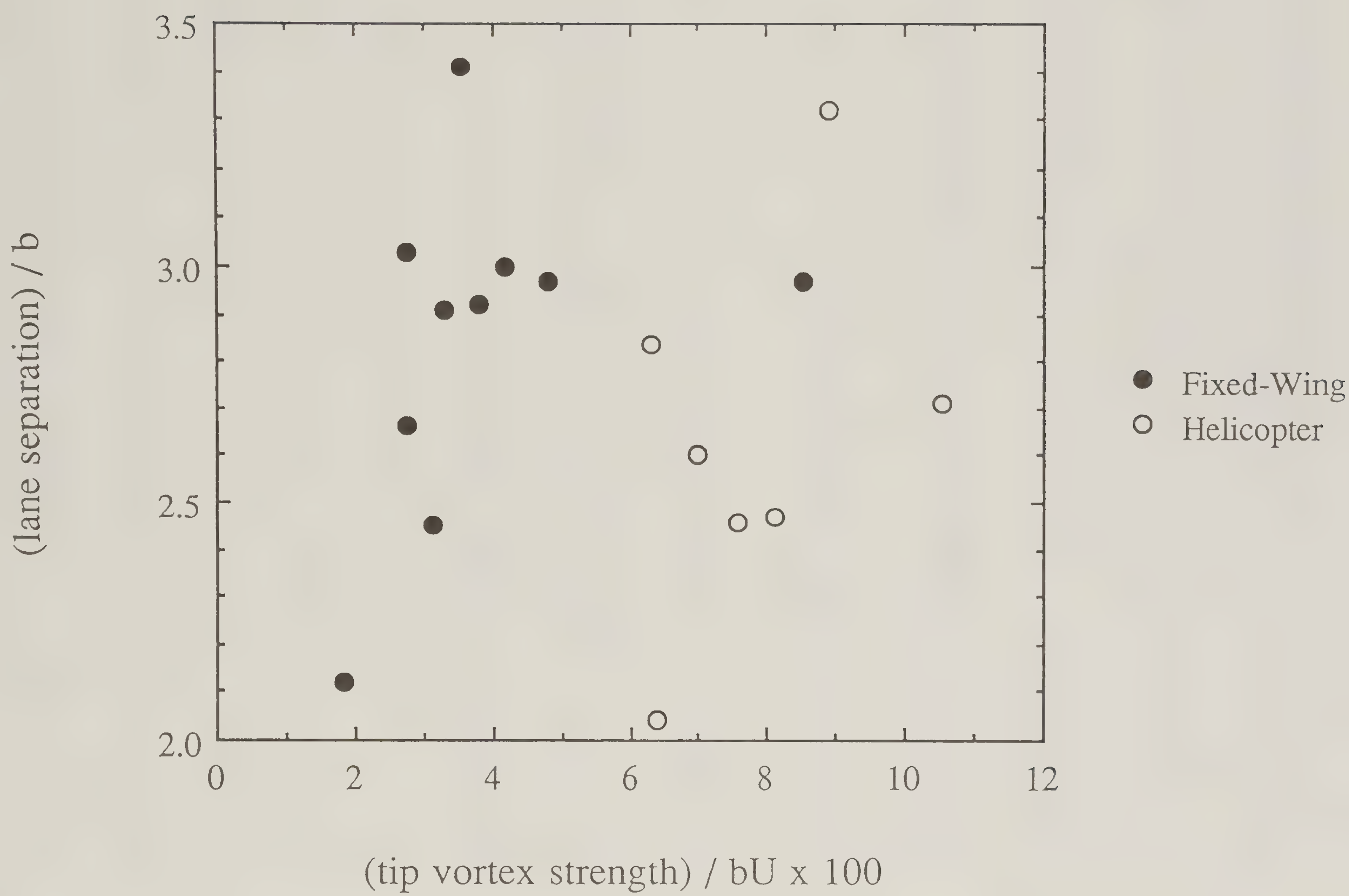


Figure 4. Lane separation for Dimilin® for all aircraft considered.

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Notes: